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MORPHOMETRY OF LANDFORMS: QUANTIFICATION OF SLOPE GRADIENTS IN GLACIATED TERRAIN

John A. Millett, et al

Army Engineer Topographic Laboratories
Fort Belvoir, Virginia

August 1972

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13. ABSTRACT

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The data of this report (from glaciated features in central Massachusetts) are intended only to implement presentation of the concept; they give no more than initial ranges of slope-gradient values for the seven features considered. Additional field measurements would extend and refine these ranges and could consider other features and other terrain factors of worldwide environments.

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MORPHOMETRY OF LANDFORMS: QUANTIFICATION OF SLOPE GRADIENTS IN GLACIATED TERRAIN

Project 1T062112A129

August 1972

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The Commanding Officer
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SUMMARY

This research note documents a concept for describing a terrain by considering it to be a composite of individual representative landforms each of which has a unique distribution of slope-gradient frequencies. By identifying landforms along a hypothetical line of movement and assigning to them slope values derived by field measurements of similar landform types in another area, the total range and frequency of the slopes that would be encountered are predicted.

The data of this research note (from glaciated features in central Massachusetts) are intended only to implement presentation of the concept; they give no more than initial ranges of slope-gradient values for the seven features considered. Additional field measurements would extend and refine these ranges and could consider other features and other terrain factors of worldwide environments.

FOREWORD

For more than a decade, the Earth Sciences Division has been concerned with the quantitative description and analysis of topographic features. The investigation summarized in this research note is a continuation of this effort applied to glaciated terrain in a mid-latitude area. It was begun while the Earth Sciences Division was an element of the U. S. Army Natick Laboratories at Natick, Massachusetts, and was completed after transfer of the Division to the U. S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia.

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MORPHOMETRY OF LANDFORMS: QUANTIFICATION OF SLOPE GRADIENTS IN GLACIATED TERRAIN

I. INTRODUCTION

Landform shapes are being measured and mapped as part of continuing Earth Sciences Division research in quantitative terrain description toward the following objectives:[1-5]

a. To provide immediate information for design, test, and use of terrain-dependent, military systems

b. To provide guidance and control for remote-imagery calibration and evaluation

c. To eventually apply the data to regional classifications of worldwide military environments.

In an antecedent study,[6] distinctive hills of glacial deposition--drumlins--were the development ground for techniques of field measurement and computerized data compilation and analysis. In this study, these measurements and techniques were extended to the individual landforms that, with drumlins, constitute the glacial terrain which characterizes the area of Massachusetts studied. Resultant data have been extrapolated to establish an initial range of characteristic values of slope gradients for a complex of landforms in glaciated terrain.

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[1] W. F. Wood and J. B. Snell, "Predictive Methods in Topographic Analysis, I: Relief, Slope, and Dissection on Inch-to-the-Mile Maps in the United States," Technical Report EP-112, Environmental Protection Research Division (EPRD), U. S. Army Quartermaster Research and Development Center, Natick, Massachusetts (1959a).

[2] ——————, "Predictive Methods in Topographic Analysis, II: Estimating Relief from World Aeronautical Charts," Technical Report EP-114, EPRD, U. S. Army Quartermaster Research and Development Center, Natick, Massachusetts (1959b).

[3] R. L. Anstey, "Physical Characteristics of Alluvial Fans," Technical Report ES-20, Earth Sciences Laboratory, U. S. Army Natick Laboratories, Natick, Massachusetts (1965).

[4] J. A. Millett and H. F. Barnett, "Surface Materials and Terrain Features of Yuma Proving Ground (Laguna, Ariz-Calif Quadrangle)," Technical Report ES-59, Earth Sciences Laboratory, U. S. Army Natick Laboratories, Natick, Massachusetts (1970).

[5] ——————, "Surface Materials and Terrain Features of Yuma Proving Ground (Red Hill, Red Bluff Mtn, and Roll Quadrangles, Ariz)," Technical Report ES-67, Earth Sciences Laboratory, U. S. Army Natick Laboratories, Natick, Massachusetts (1971).

[6] H. F. Barnett and P. G. Finke, "Morphometry of Landforms: Drumlins," Technical Report ES-63, Earth Sciences Laboratory, U. S. Army Natick Laboratories, Natick, Massachusetts (1971).

Although this study is concerned with one terrain parameter—slope gradient—the concept of data analysis and synthesis is applicable to many terrain parameters that might affect tactical or materiel problems.

II. OBJECTIVE

The objective of this study is to develop and demonstrate a method for estimating slope-gradient values and frequencies for a given terrain by considering them to comprise weighted values and frequencies from component individual landforms.

III. APPROACH

The approach is as follows:

a. To delineate the landforms which make up the regional terrain. In this study, a glaciated terrain in Massachusetts was chosen for which landforms were delineated on a published geologic map.[7]

b. To measure the component landforms in a field sample area to establish slope-gradient frequencies for each.

c. To establish slope-gradient frequency distributions for the regional terrain by weighting areal occurrences of component landforms by the slope frequencies measured on each landform in the field sample area.

For this pilot study, the approach assumes that each distinctive glaciated landform (a drumlin, for example) has a distinctive frequency distribution of slope gradients wherever the feature is found. The data collected in the field for this study appear to bear out that assumption and constitute initial ranges of values which should be refined by additional field measurements. The data are representative of a terrain type recognizable in glaciated regions by the presence of drumlins which are features indicating a unique combination of pressure, rate of movement, and kinds of rock materials of moving glacial ice.

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[7] W. R. Hansen, "Geology and Mineral Resources of the Hudson and Maynard Quadrangles, Massachusetts," U. S. Geological Survey Bulletin 1038 (1956).

IV. METHODS

Slopes on representative landforms of glacial origin in a sample area of Massachusetts were measured in the field with a hand-held Abney level accurate to 1 degree and a hand-held Dietzgen optical rangefinder accurate to 2 percent. Traverses were taken parallel with or normal to apparent directions of movement of the depositional agent (glacial ice) on each of seven landforms: drumlins, eskers, kames, kame terraces, kettles, ground moraine, and outwash plain. An eighth landform, composed of marshes and low river terraces whose slopes are all less than 2 degrees, was not traversed. Figure 1 is a portion of the surficial geology map of the combined Hudson and Maynard quadrangles, Massachusetts, with the sample area outlined at the bottom center.

Slope-measurement data, consisting of gradients in degrees and distances in feet, were compiled to establish distributions of slope-gradient values and frequencies for each landform. From these compilations, histograms showing slope frequency (by 3-degree class intervals) as percent of the total traverse distance were constructed for each landfrom (Figs. 2 through 7), excluding the marshes and low river terraces unit and the outwash plains unit. (All slopes on these two units are less than 2 degrees and histograms would consist of only one bar.)

Table I shows the distances traversed in each unit and the number of landforms measured (if applicable).

Table I. Traverses in Sample Area by Landforms
(see Fig. 1)

Landform	Map Symbol	Traverse Length (ft)	% of Total Length	Number of Landforms Measured
Drumlin	Qd	4,119	26.3	2
Esker	Qe	217	1.4	1
Kame	Qk	527	3.4	2
Kame Terrace	Qkt	1,161	7.4	–
Kettle	–	501	3.2	1
Ground Moraine	Qgm	8,710	55.8	–
Outwash Plain	Qop	397	2.5	–
Total Length		15,632		

Fig. 1. Part of the surficial geology map of the Hudson and Maynard Quadrangles, Massachusetts, showing the field sample area. (Note: Qd = drumlin; Qe = esker; Qk = kame; Qkt = kame terrace; Qgm = ground moraine; Qop = outwash plain.)

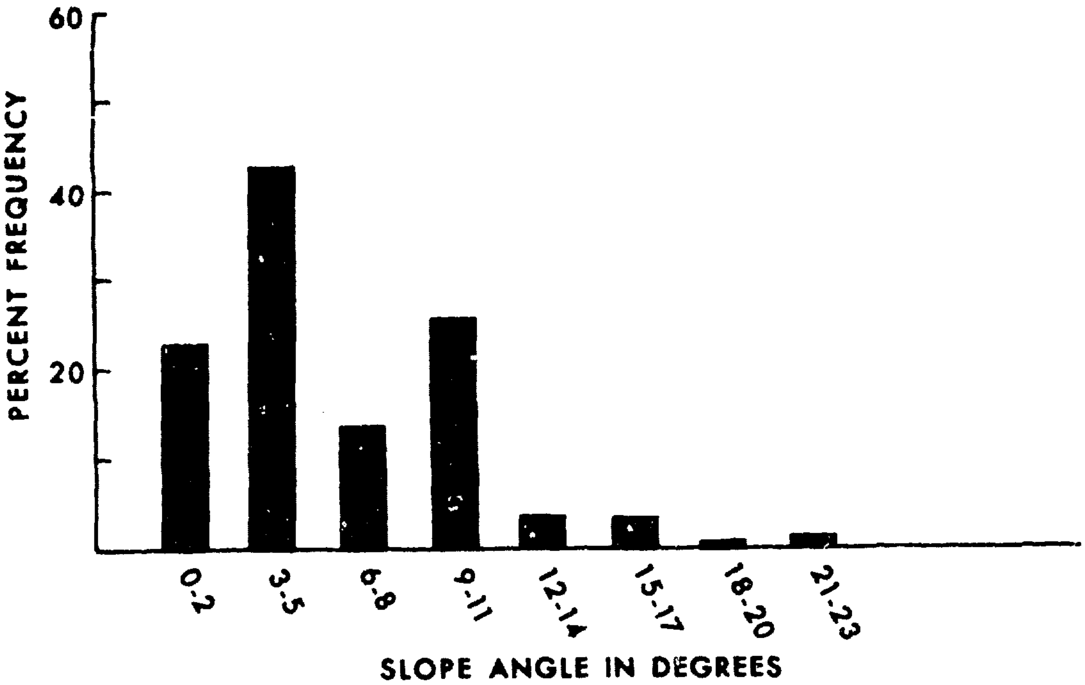

Fig. 2. DRUMLIN (Qd): Frequency of slope gradients (by 3-degree classes, as percent of total traverse distance) (5-72).

Fig. 3. ESKER (Qe): Frequency of slope gradients (by 3-degree classes, as percent of total traverse distance) (5-72).

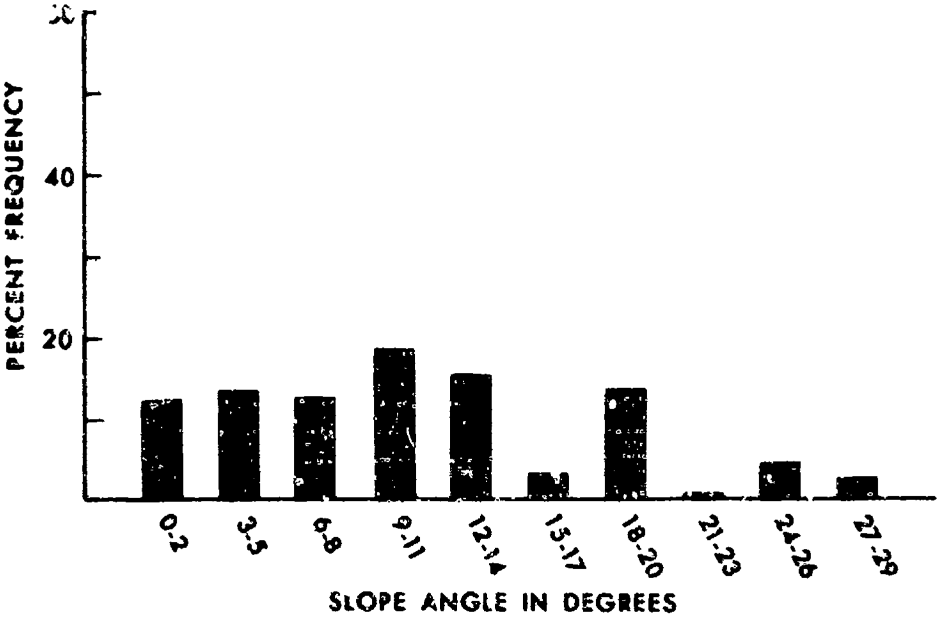

Fig. 4. KAME (Qk): Frequency of slope gradients (by 3-degree classes, as percent of total traverse distance) (5-72).

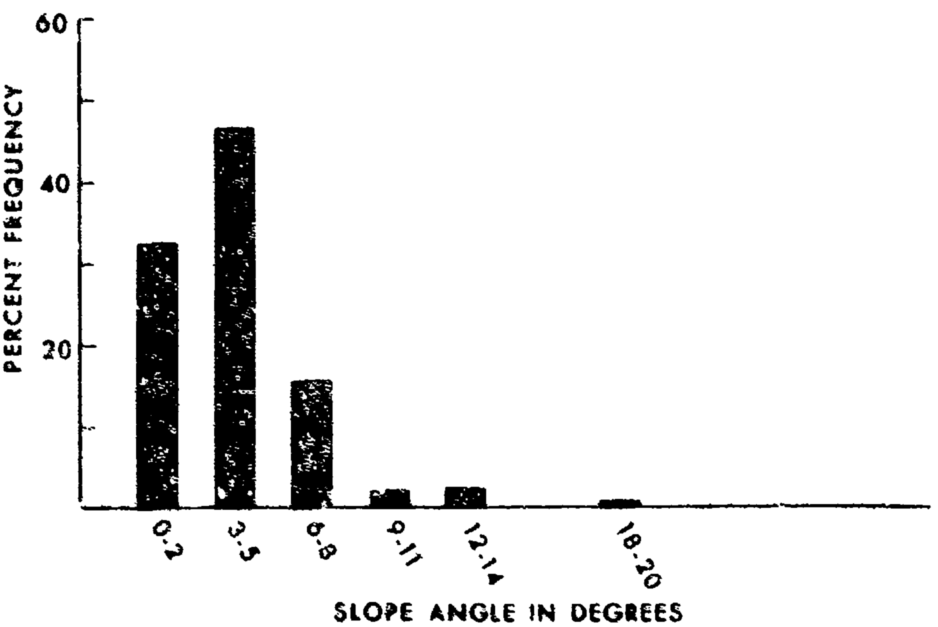

Fig. 5. KAME TERRACE (Qkt): Frequency of slope gradients (by 3-degree classes, as percent of total traverse distance) (5-72).

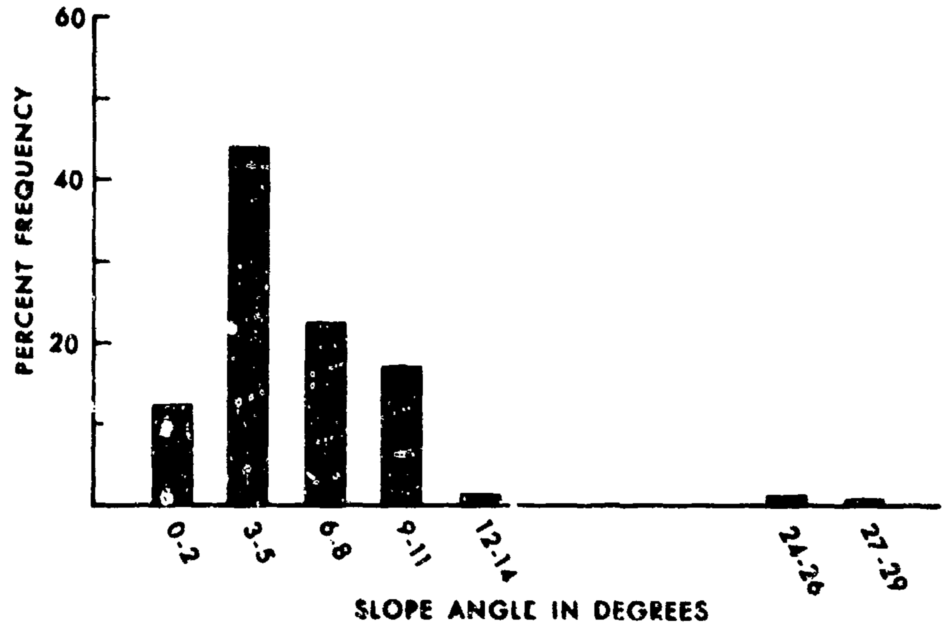

Fig. 6. KETTLE: Frequency of slope gradients (by 3-degree classes, as percent of total traverse distance) (5-72).

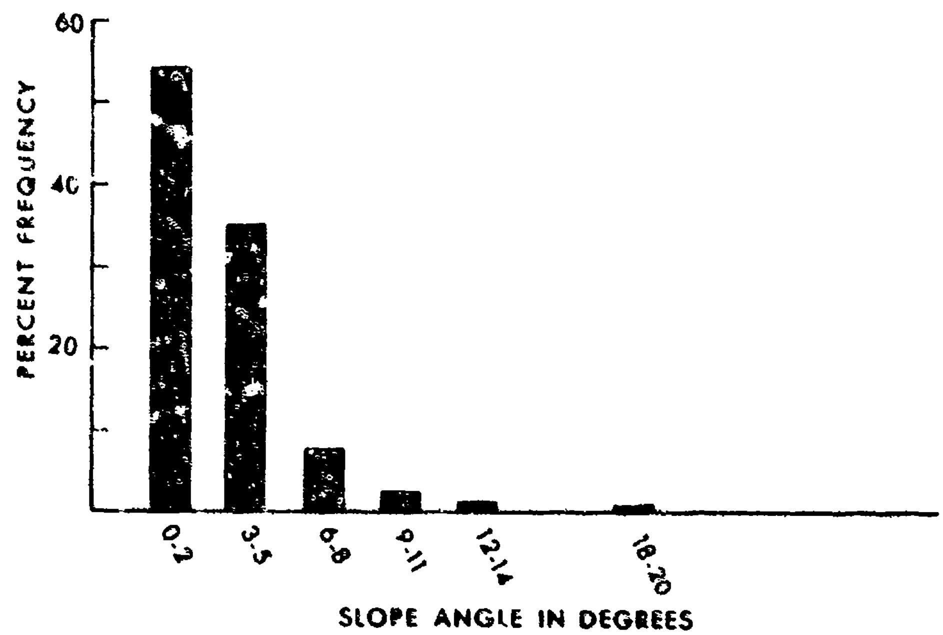

Fig. 7. GROUND MORAINE (Qgm): Frequency of slope gradients (by 3-degree classes, as percent of total traverse distance) (5-72).

Table II. Slope-Gradient Frequencies from Field Measurements in a Sample Area of Massachusetts
(by 3-degree classes, as percent of total traverse distance on each landform)

Landform	Map Symbol	Slope-Gradient Classes (in degrees)									
		0-2	3-5	6-8	9-11	12-14	15-17	18-20	21-23	24-26	27-29
Drumlin	Qd	22.7	42.9	13.9	25.5	3.5	3.3	0.9	1.2	—	—
Esker	Qe	1.3	5.2	2.6	9.2	7.8	33.9	17.6	—	17.9	4.5
Kame	Qk	12.4	13.4	12.8	18.7	15.4	3.3	13.7	0.7	4.5	2.4
Kame Terrace	Qkt	32.5	46.3	15.9	2.1	2.4	—	0.8	—	—	—
Kettle	—	12.4	44.1	22.6	17.1	1.6	—	—	—	1.2	1.0
Ground Moraine	Qgm	54.2	35.1	7.8	2.5	1.3	—	0.9	—	—	—
Outwash Plain	Qop	100.0	—	—	—	—	—	—	—	—	—
Marshes and Low River Terraces	—	100.0	—	—	—	—	—	—	—	—	—

Note: This table can be used to predict the frequencies of slope gradients along any chosen traverse by applying the above frequencies weighted by the frequency of occurrence of the landforms along the traverse.

Table II shows slope-gradient frequencies for the landforms measured in the Massachusetts field sample area.

Because the field sample area was small (1.86 sq mi), a larger nearby area (36.8 sq mi) of the same Hudson-Maynard quadrangles (including the small area) was chosen as representing more adequately the areal distribution of landforms in the glaciated terrain. Areas of individual landforms were measured with a planimeter (Table III).

Table III. Distribution of Landforms in Sample Areas
(as percents of total areas)

Landform	Map Symbol	Distribution small sample area (1.86 sq mi)	Distribution larger sample area (36.8 sq mi)
Drumlin	Qd	5.9	10.7
Esker	Qe	0.3	1.1
Kame	Qk	0.3	5.0
Kame Terrace (and Kame Plain)	Qkt	18.3	19.6
Ground Moraine	Qgm	55.8	27.6
Kettle	–	–	–
Outwash Plain (and Outwash Terrace)	Qop	7.0	13.8
Marshes and Low River Terraces	–	12.4	18.9
Ponds and Rivers	–	–	3.3

The areal distribution of landforms for the larger sample area (corrected to remove the 3.3 percent of water areas) was used with the slope-gradient frequencies in Table II to compile a histogram characterizing the frequency distribution of gradients in the glaciated terrain (Fig. 8).

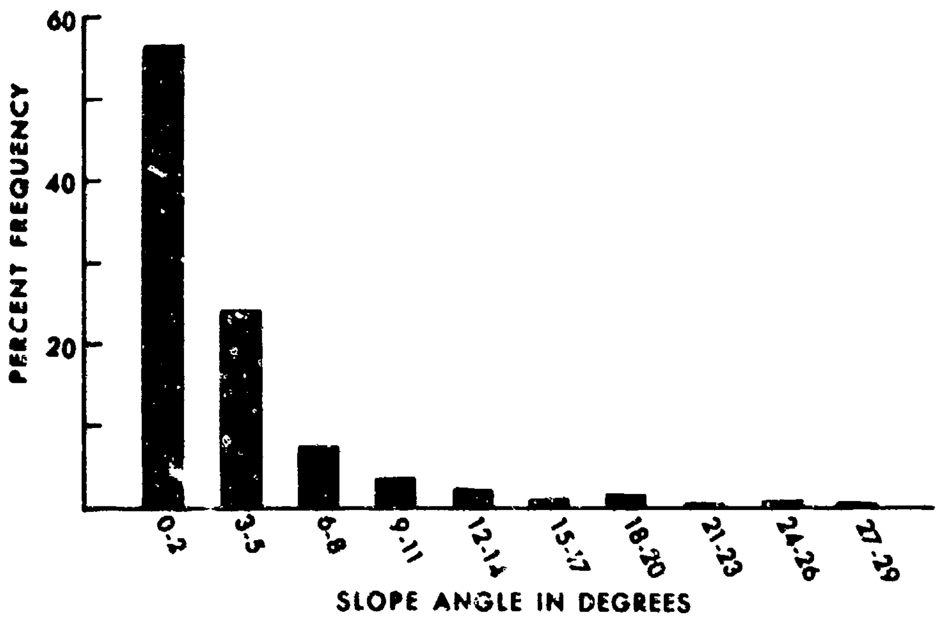

Fig. 8. Frequency distribution of slope gradients in the larger sample area excluding water areas.

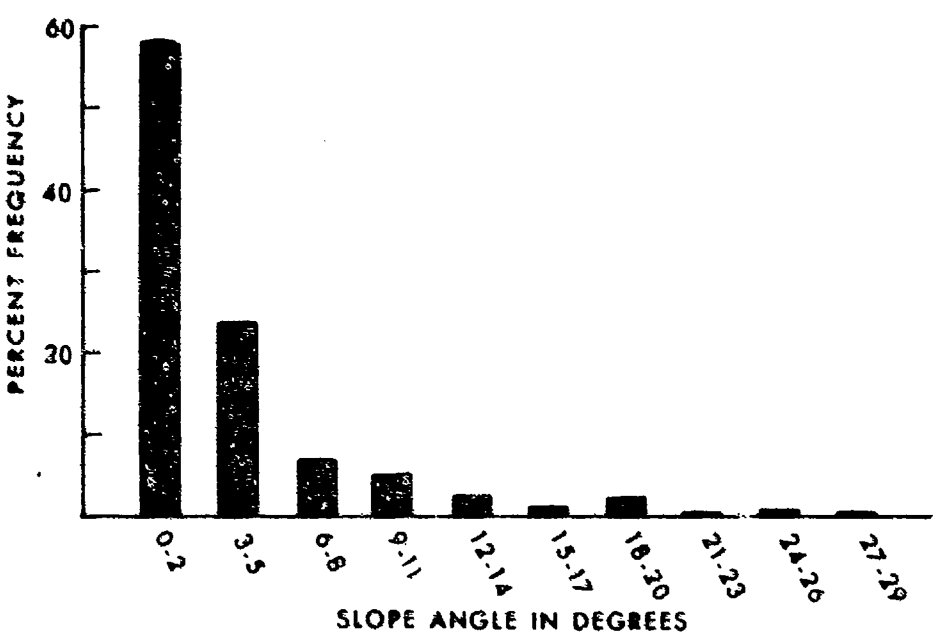

Fig. 9. Slope gradients to be expected along hypothetical "axis of advance" in glaciated terrain (5-72).

V. APPLICATION

The technique suggested in this study could be applied to a variety of military problems for many terrain parameters. An example of possible application is the prediction of slopes along a line such as a tactician's "axis of advance." To illustrate this application, a 3-mile-long traverse was chosen on the Hudson-Maynard, Massachusetts, surficial geology map. Table IV shows the occurrence of the landform mapping units along the traverse and the percent of total traverse distance each represents.

Table IV. Occurrence of Landforms Along a Hypothetical "Axis of Advance" in Glaciated Terrain (as percent of total traverse distance)

Landform	Map Symbol	Distance Along Traverse (mi)	Percent of Total Traverse Length
Druralin	Qd	0.24	8.0
Esker	Qe	0.06	2.0
Kame	Qk	0.24	8.0
Kame Terrace	Qkt	0.25	8.2
Ground Moraine	Qgm	1.31	43.8
Marshes and Low River Terraces	–	0.90	30.0
Total Traverse Length		3.00	

Using these percentages and the slope-gradient frequencies in Table II, a histogram (Fig. 9) has been constructed to indicate the magnitudes and frequencies of slope gradients to be expected along the hypothetical axis of advance.

VI. CONCLUSIONS

The approach outlined in this report is useful for predicting slope-gradient frequencies in a glaciated terrain composed of recognizable, individual landforms. It should be equally useful in any other terrain for which representative frequencies of landform slopes are available. Because each landform (or association of related surface characteristics) is treated as an independent module of terrain data, it is not necessary for a region to be classified in any detail beyond that which is helpful in recognizing landforms.

This study was begun with the assumption that each distinctive, glaciated landform has a distinctive, slope-gradient distribution. The histograms presented here, as well as the tabular frequency data, are visibly different for each distinctive landform suggesting that the assumption was valid. If, however, the slope distributions on some landforms were similar, the approach would still be useful (and, in fact, would require fewer calculations for a given region) in that predictions are derived only from known representative slope occurrences that are unrelated in this usage to geomorphic designations or implications. If, for example, slopes on a kame are similar to those on a small cinder cone, the data also are similar and the name or origin of the feature is immaterial.

The technique for calculating slope occurrences takes few measurements and little time and can be used with maps and airphotos. The usefulness of the results depends upon correct identification of landforms and upon the number of available representative ground measurements of similar landforms.